Non-reciprocity and quantum correlations of light transport in hot atoms via reservoir engineering

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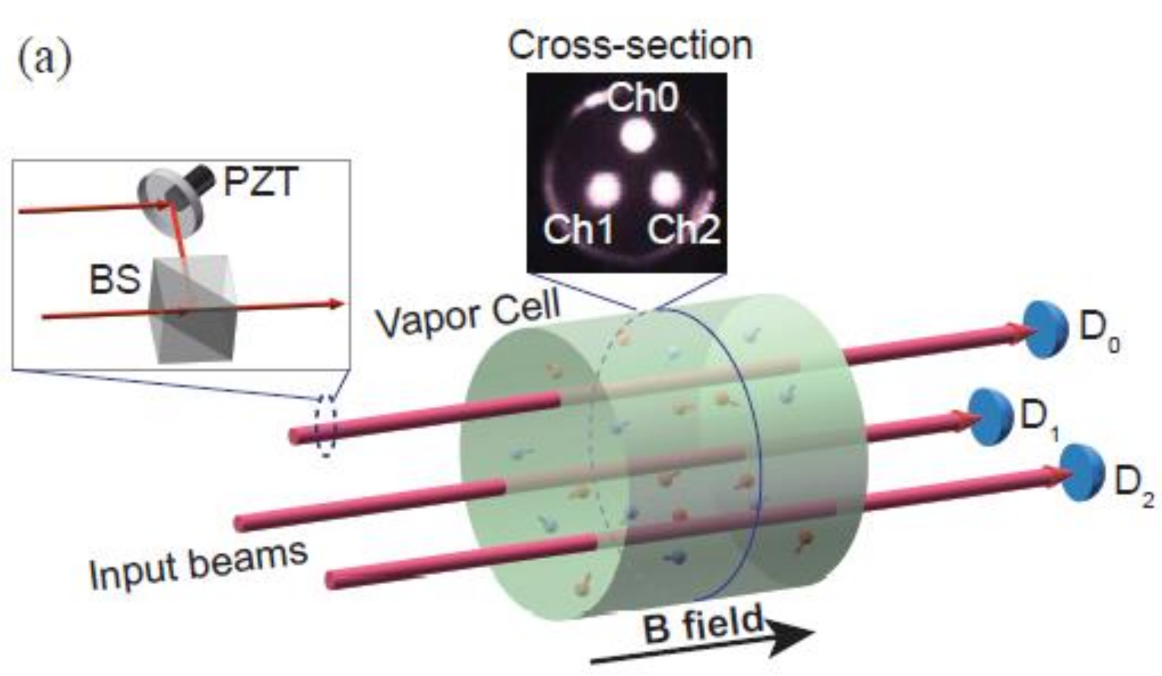
Abstract: The breaking of reciprocity is a topic of great interest in fundamental physics and optical information processing applications. We demonstrate non-reciprocal light transport in a quantum system of hot atoms by engineering the dissipative atomic reservoir. Our scheme is based on the phase-sensitive light transport in a multi-channel photon-atom interaction configuration, where the phase of collective atomic excitations is tunable through external driving fields. Remarkably, we observe inter-channel quantum correlations which originate from interactions with the judiciously engineered reservoir. The non-reciprocal transport in a quantum optical atomic system constitutes a new paradigm for atom-based, non-reciprocal optics, and offers opportunities for quantum simulations with coupled optical channels.

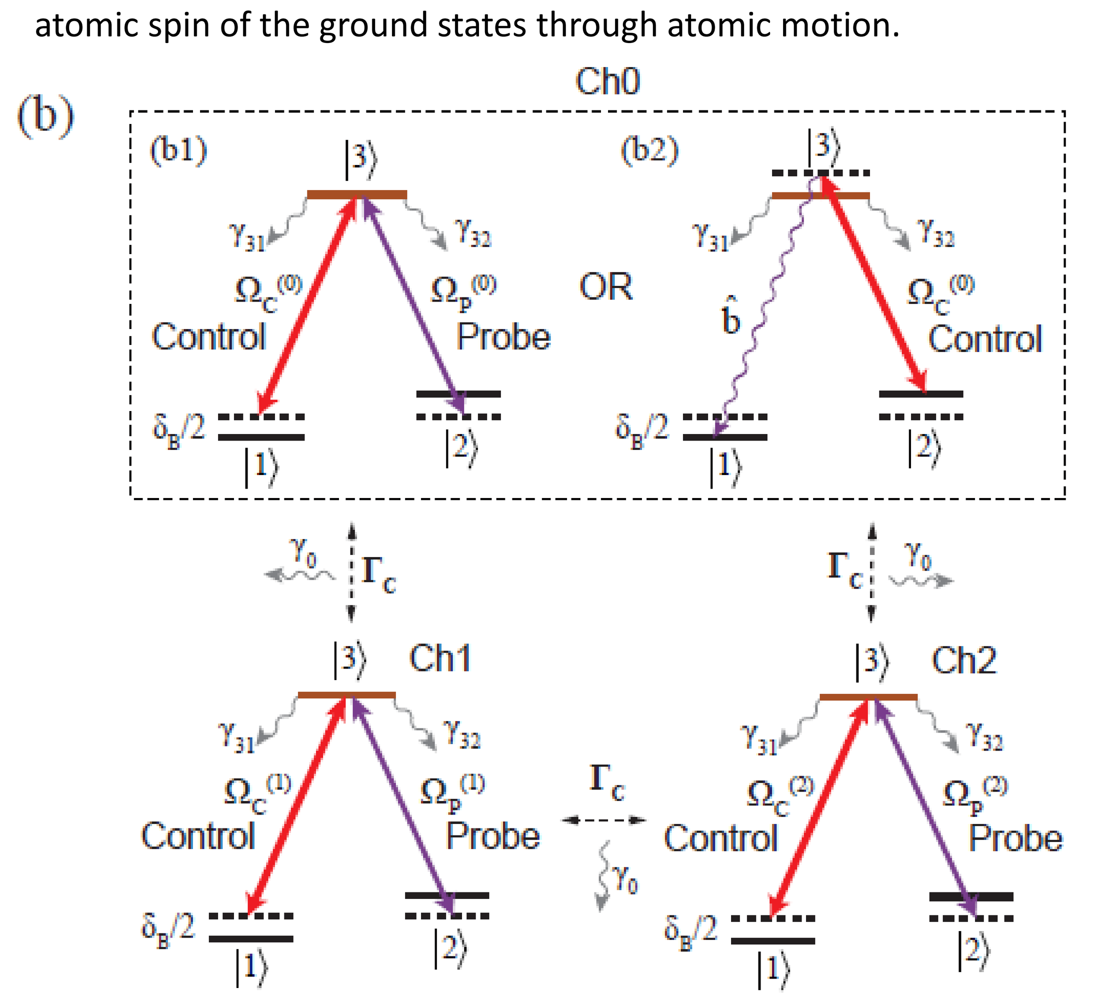
Experimental Setup

(a)



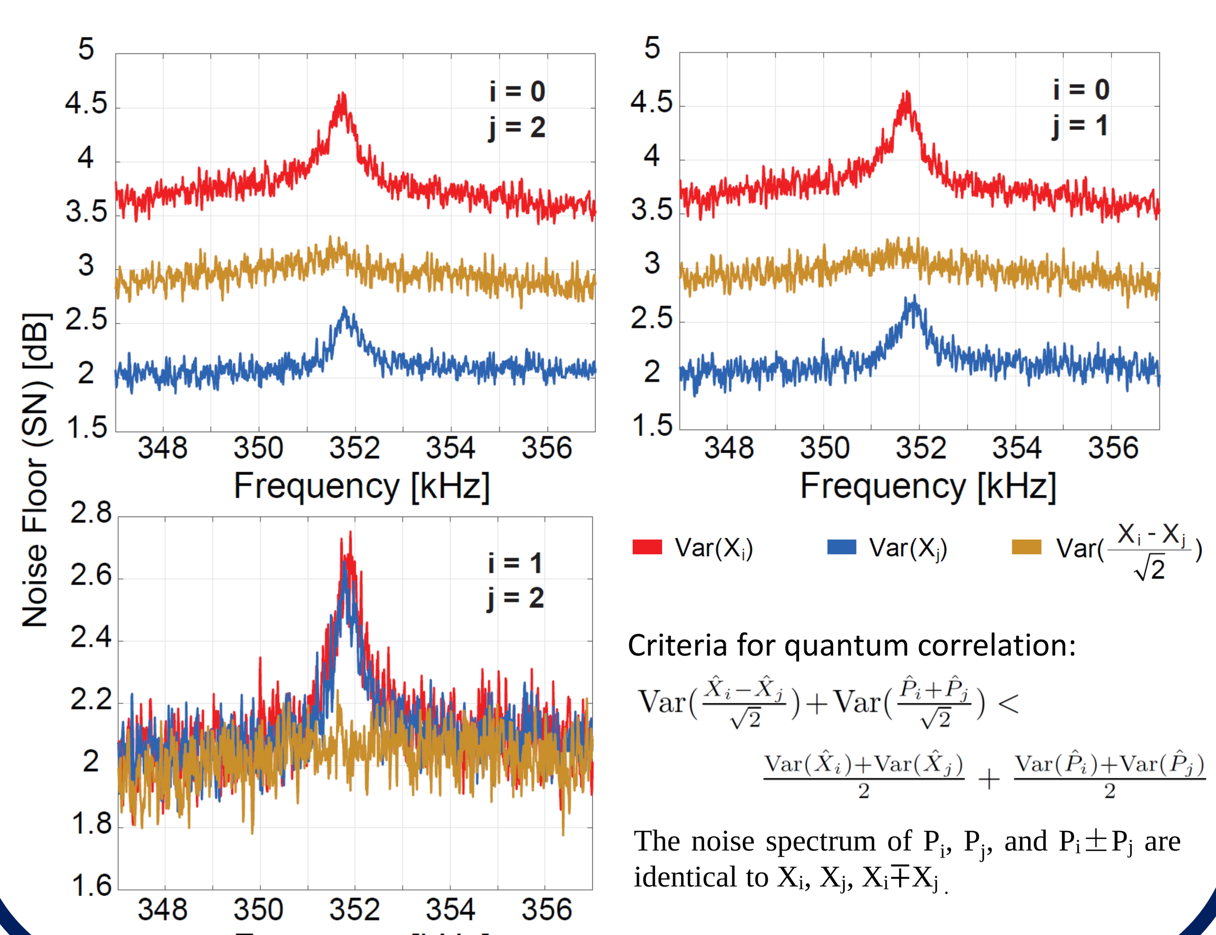
Experiment schematics. Three spatially separated optical channels propagate in a warm paraffin-coated Rb^{87} vapor cell under EIT interaction. The inter-channel couplings are mediated by the mixing of atomic spin of the ground states through atomic motion.

(b)



The three-level scheme in three channels. The ground states are Zeeman sublevels of F = 2, and the excited state is F = 1 of the 87Rb^{87} D1 line. In the measurements of quantum fluctuation, all three weak probes are removed as shown in (b2) (Ch1 and Ch2 are not shown).

Quantum correlations



Criteria for quantum correlation:

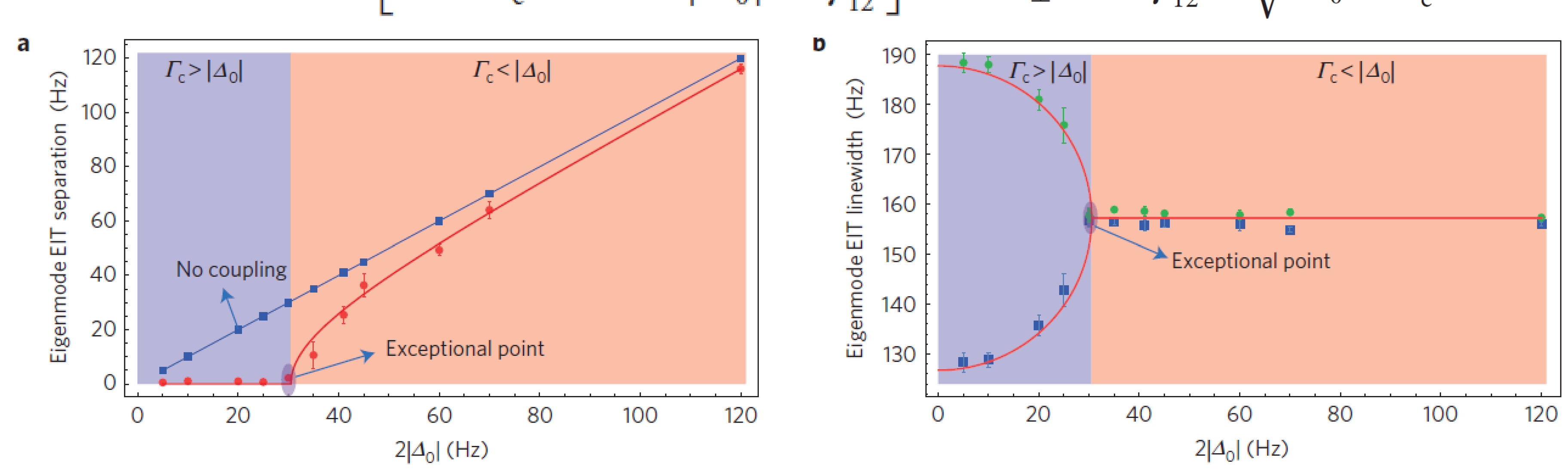
$$\mathrm{Var}\left(\frac{\hat{X}_i-\hat{X}_j}{\sqrt{2}}\right)+\mathrm{Var}\left(\frac{\hat{P}_i+\hat{P}_j}{\sqrt{2}}\right) < \frac{\mathrm{Var}(\hat{X}_i)+\mathrm{Var}(\hat{X}_j)}{2} + \frac{\mathrm{Var}(\hat{P}_i)+\mathrm{Var}(\hat{P}_j)}{2}$$

The noise spectrum of P_i, P_j, and $P_i \pm P_j$ are identical to X_i, X_j, $X_i \mp X_j$.

Hamiltonian with Non-Hermitian Coupling

① Atoms: $H' = \begin{bmatrix} |\Delta_0| - i\gamma'_{12} & i\Gamma_c \\ i\Gamma_c & -|\Delta_0| - i\gamma'_{12} \end{bmatrix}$

Eigenvalues: $\omega_\pm = -i\gamma'_{12} \pm \sqrt{\Delta_0^2 - \Gamma_c^2}$



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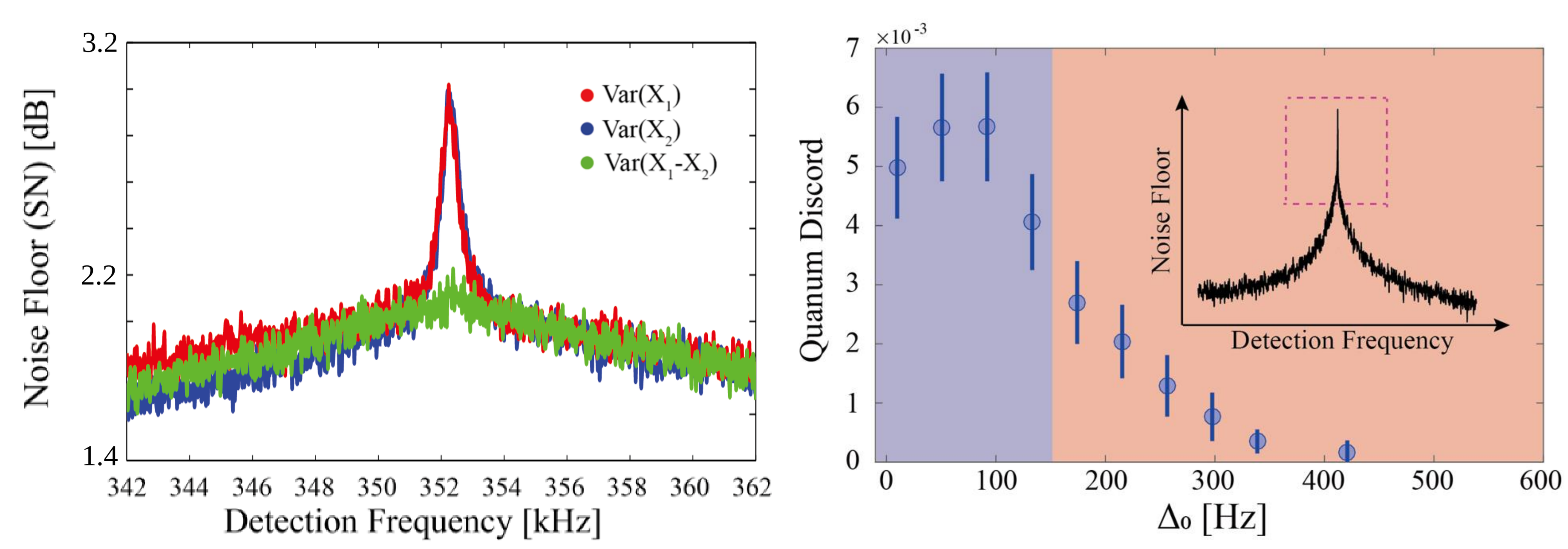
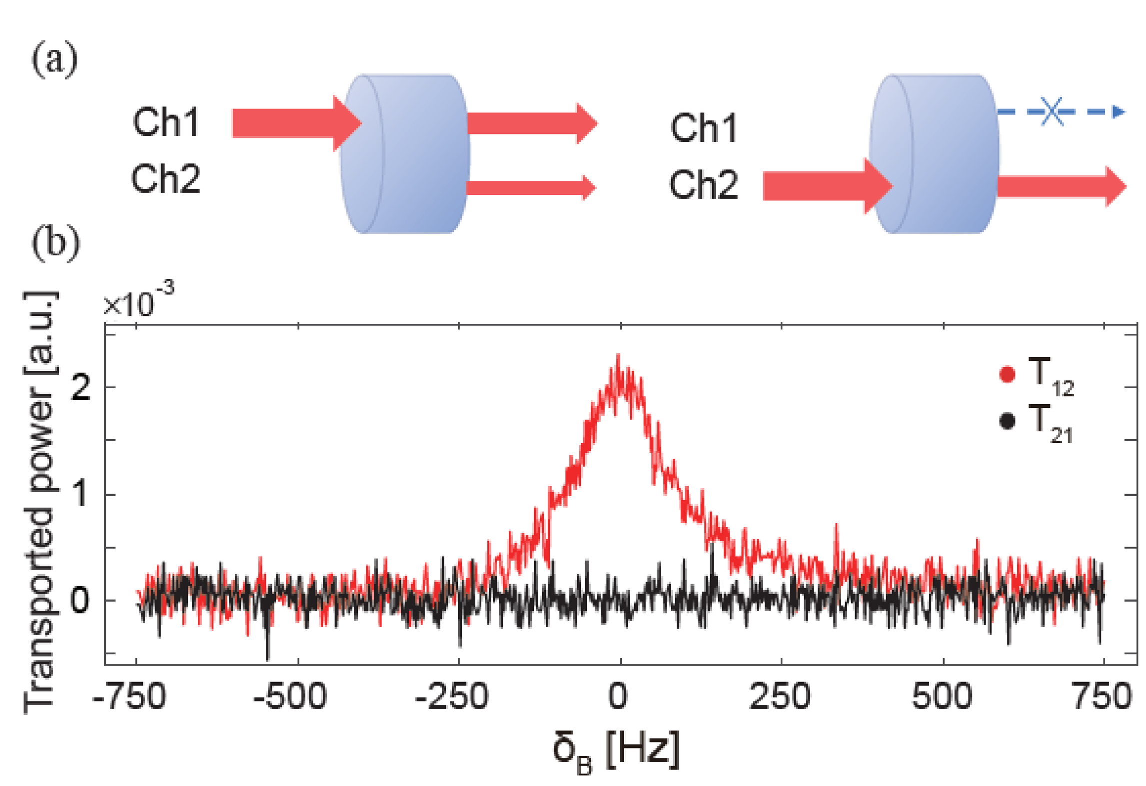
② Photons(1): CH1: $\hat{H}_1 \propto \hat{a}_1^\dagger \hat{S}^\dagger + h.c.$; CH0: $\hat{H}_2 \propto \hat{b}^\dagger \hat{S} + h.c.$ } Two-mode squeezing: $H \propto \hat{a}_l^\dagger \hat{b}_u^\dagger + h.c.$



Wanxia Cao, Xingda Lu, Xin Meng, Jian Sun, Heng Shen, and Yanhong Xiao, Reservoir-mediated quantum correlations in non-Hermitian optical system, ***Phys. Rev. Lett.*** 124, 030401 (2020)

③ Photons(2): CH1: $\hat{H}_1 \propto \hat{a}_1^\dagger \hat{S}^\dagger + h.c.$; CH2: $\hat{H}_2 \propto \hat{a}_2^\dagger \hat{S}^\dagger + h.c.$ } Beam splitter: $H \propto \hat{a}_1^\dagger \hat{a}_2 - h.c.$



$$H_{eff} \propto \sum_{i,j}^{i\neq j} \hat{a}_i^\dagger \hat{a}_j e^{-i\varphi_{ij}} - \hat{a}_i \hat{a}_j^\dagger e^{i\varphi_{ij}}$$

(a) Schematics of the non-reciprocal transport.
(b) Transport spectrum. The two-photon detuning δ_B is proportional to the applied common magnetic field.

Red curve T_{12} is the transported power from Ch1 to Ch2 when injecting the weak probe in Ch1. Black curve T_{21} is the transported power from Ch2 to Ch1 when injecting the weak probe in Ch2. The local phase of all three channels is set to be: θ_0 = 0, θ_1 = 0 and θ_2 =π. The input power of the probe in each channel is 50 μW. The input power of the control in each channel is 500 μW. The cell temperature is 60C.

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